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Evaluating multi-axes sun-tracking system at different modes of operation in Jordan

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Abstract

A concise overview on recent research work on sun-tracking system is presented. Also, an experimental investigation on the effect of using multi-axes sun-tracking systems on the electrical generation of a flat photovoltaic system (FPVS) was carried out to evaluate its performance under Jordanian climate. Multi-axes (N–S, E–W, vertical) electromechanical sun-tracking system was designed and constructed. The measured variables were compared with that at fixed axis. It was found that there was an overall increase of about 30–45% in the output power for the North–South axes (N–S)-tracking system compared to the fixed PV system. Also, it was found that the N–S axes sun tracking is the optimum.

Keywords: Photovoltaic systems; Power generation; Sun-tracking devices; Solar energy

Contents

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1. Introduction

Jordan is non-oil-producing country and the sharp increase in the prices of oil is forcing the country to seek for other alternative sources for energy (i.e. solar, wind). The solar energy is becoming more and more a viable source of energy for many industrial and housing appliances. Therefore, sun-tracking systems is an attractive choice to explore. There are several types of these systems classified based on their kinematic motion, type of collector, absorber type, concentration ratio and indicative temperature range. These systems are summarized as follows:

1) *Stationary*: flat plate collector (FPC), evacuated tube collector (ETC), compound parabolic collector (CPC), and photovoltaic (PV) panels.
2) *Single-axis tracking*: CPC, linear Fresnel reflector (LFR), parabolic trough collector (PTC), cylindrical trough collector (CTC).
3) *Two-axes tracking*: parabolic dish reflector (PDR) and heliostat field collector (HFC).

For further information, excellent reviews on the use of renewable energy in various types of desalination systems and a survey of the various types of solar thermal collectors and applications were presented by Kalogirou [1,2], Sukhatme [3], Duffie and Beckman [4], and Hu and White [5]. An evaluation study, and an overview on the up to date research on the applications of various sun-tracking systems has been done to give a clear picture on present research status.

2. Sun-tracking systems: an overview

As the sun's position changes hourly, the solar power devices should be adjusted to produce the maximum output power. Single-axis-tracking systems are considerably cheaper and easier to construct, but their efficiency is lower than the two axes sun-tracking systems. An early work by Neville [6] presented a theoretical comparative study between the energy available to a two axes tracker, an East–West (E–W) tracker and a fixed surface. Hession and Bonwick [7] introduced a sun-tracking system for use with various collectors and platforms.

For solar concentrator systems as well as for radiometric measurement of the solar radiation, the tracking of the sun is necessary. Conventional trackers periodically update the orientation of the device to the actual position of the sun. Schubnell and Ries [8] presented an approach controlling the angular velocity of the tracking device. The question of how to construct a sun-tracking structure for concentration PV was addressed by Davies [9], through the use of the familiar equatorial axis and a second

axis perpendicular to the ecliptic plane. Where, Duffie and Beckman [4] indicated that the evaluation of PV systems and the design of power systems based on solar cells must be based on the voltage–current relationships under various levels of radiation and temperatures.

For evaluating various PV modules, Hirata and Tani [10,11] described "the spectral method" used for evaluating the maximum amount of output in these modules, and investigated how changes in spectral solar radiation affect the output of PV modules, also they examined the seasonal changes of PV module output. Parretta et al. [12] analyzed the energetic losses, relative to the standard conditions of testing, in PV modules in outdoor operation. Whereas, Baruch et al. [13], derived the upper limits of theoretical conversion efficiency for a PV solar cell either through a thermodynamic argument involving energy and entropy balance.

Lodhi [14] reviewed the solar PV technology in a semi-technical manner with special reference to materials used and devices designed. Whereas, Barua [15] reviewed the status of different thin film PV technologies viz: (1) amorphous silicon, (2) polycrystalline thin film and (3) silicon film.

The cost for small PV pumping systems can be reduced by using optical concentrators to reduce the cost of solar electricity, and by developing more efficient pump/motor/controller systems [16].

Prakash and Bansal [17] evaluated the energy consumption in solar PV (SPV) module production in India and examined its implications for large-scale plants. Also, Kamel [18] presented a basic study on the possibilities of the contribution of SPV to provide power in an existing electrical grid in Egypt.

For sun-tracking collector, Ibrahim [19] conducted experimental investigation on a collector consisting of six parabolic troughs. Whereas, Kalogirou [20] described a tracking system which can be used with single-axis solar-concentrating systems. The position and "status" of the sun are detected by three light-dependent resistors (LDRs), one of which detects whether the collector is focused, whilst a second resistor determines if there is cloud cover, and the third senses whether it is day or night.

Khalifa and Al-Mutwalli [21] performed an experimental study to investigate the effect of using two-axes sun-tracking system on the thermal performance of compound parabolic concentrators CPC. The tracking of CPC collector showed a better performance with an increase in the collected energy of up to 75% compared with an identical fixed collector. Also, Shah et al. [22] reviewed the advantages and limitations of SPV modules for energy generation with their operation principles and physical efficiency limits.

Hegazy [23] carried out an extensive investigation of the thermal, electrical and overall performances of flat plate PV/thermal (PV/T) air collectors.

Multi-axes sun-tracking (MAST) system can be applied in all types of solar systems to increase their efficiency. MAST of the PV systems have not seen the intensive research and development activity; however some researchers investigated the effect of using MAST systems controlled by a modern computerized control system such as PLC. Barakat et al. [24] used a two axes sun tracking with closed loop system but with complicated electronic control circuits. They found that the energy available to the two axes tracker is higher by 20%. Sandnes and Rekstad [25] used a polymer solar heat collector combined with single-crystal silicon PV cells in a hybrid energy-generating unit which simultaneously produced low-temperature heat and electricity. The PV/T unit was tested experimentally to

determine its thermal and PV performance, in addition to the interaction mechanisms between the PV and thermal energy systems. Thermal efficiency measurements for different collector configurations were compared, and PV performance and temperature readings were presented.

Alferov et al. [26] discussed the key areas in the development of PV methods of solar energy conversion. The authors highlighted the PV devices which have now matured scientifically and technologically to such an extent that they may be regarded as a technical basis for large-scale solar power generation in the future.

Roth et al. [27,28] constructed and tested a sun-following system. The tracker gives the possibility for automatic measuring of direct solar radiation with a pyrheliometer. The mechanism is operated by a digital program in the control system, situated separately from the mechanical part. The position of the sun is calculated, and the pointing errors appearing during its daffy work are stored for later analysis. The experiments showed good results.

The aims of the present experimental study were as follows: firstly to design and build a MAST systems for PV cells using the cheapest available resource. Secondly to conduct experimental trials on the designed tracking and fixed systems to establish the PV performance enhancement under Jordanian climate.

3. Experimental setup

In this work, the PLC-controlled system for the MAST was designed and constructed. The system consists of a simple electromechanical setup, having low cost, and maintenance, and easily installed and assembled. Pyranometers were mounted on platforms controlled by present system to investigate the availability of solar radiation on tracking surfaces. The PLC method of control programmable memory in which instructions were stored to implement various functions used to control actuation of processes. The programming was based on the solar angles analysis, which moves the tracking surface into the calculated positions.

4. Programming method of control with open loop system

Closed loop systems with photo sensors are traditionally used as a main method of control of sun-tracking systems. The photo sensors used to track the sun position and to send the electrical signals proportional to the error to the controller, which actuate the motor to track the sun, similar to the system used by other researchers [29,30]. In this research the programming method of control works efficiently in all weather conditions regardless of the presence of clouds. The calculated values of the surface positions as a function of time were fed to the PLC program to control the actuator of the sun position tracker.

Mathematically, the surface position is defined by two angles β and γ [4]. β is the slope of the surface, and γ is the surface azimuth angle, Fig. 1. For two-axes tracking, surface positions are determined as follows: $\beta = \theta_z$ and $\gamma = \gamma_s$ where θ_z is the zenith angle of the sun and γ_s is the sun azimuth angle. Multi sun tracking motors are used, one for the joint rotating about the horizontal north–south (N–S) axis or E–W axis to control β, and the other motor for the joint rotating about the vertical axis to control γ.

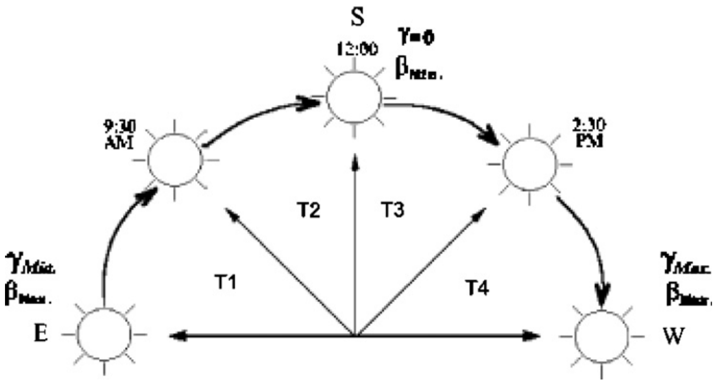

Fig. 1. The division of daylight time into four intervals.

5. The electromechanical system

The electromechanical system consists of two drivers: the first for the joint rotating about the vertical axis as shown in Fig. 2 and the second for the N–S or E–W tracking shown in Fig. 3. It can be seen from Fig. 2 that the system has two bridge rectifiers. The first one, PS1, converts the 220 VAC of supply network into 24 VDC to power the PLCI. The second rectifier, PS2, converts 220 VAC into 24 VAC to supply the electrical motor M1.

PLCI system chosen was of the LOGO 24 RC type [31,32] because it suits this application. Also, it is fairly simple and cheap in cost. The components of Fig. 3 are the same as in Fig. 2, except that the voltage of M2 is 36 VDC with a worm gear instead of 24 VAC with a spur gear as in Fig. 2. The present stepwise tracking simplifies the work of the system without great loss in power. The estimated consumed power by the electrical motor and control system is less than 3% of the collected energy by the tracking system.

6. Control system programming

Computer software has been developed to determine the different solar angles for Amman, to calculate the optimal positions of the tracking surface during the daylight hours. Daylight hours were divided into 4 identical time intervals $T1$, $T2$, $T3$ and $T4$, as shown in Fig. 1, during which the motors speeds (deg./second) were determined. Then, the PLC programming was done based on the solar angles analysis and motor speed calculations. The PLC controls the intermittent position adjustments made by the motors, which means that the motor of N–S and E–W tracking will be idle for 5–10 min according to the different intervals of time mentioned above and works only for few seconds. The motor of vertical tracking will be idle for 15–35 min and works for a few seconds. As well, the LOGO 24 RC PLC system uses the functional diagram language of programming described in [31,32].

Two types of motions were specified by the developed program: forward motion and backward motion. From the theoretically calculated values the forward motion covers the intervals of time $T1$ and $T2$ in Fig. 1. While the backward motion will cover the intervals $T3$ and $T4$ which begin from noon till sunset where β is maximum.

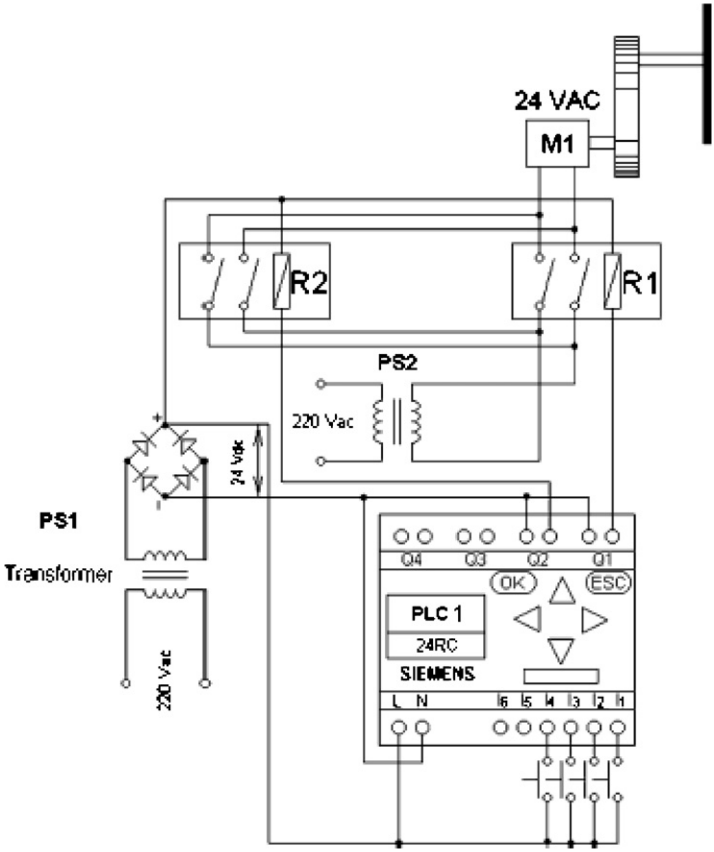

Fig. 2. The electromechanical circuit for vertical control.

7. Outcome results

Measurements on the PV system with and without sun tracking at two different climatical conditions are shown in Figs. 4 and 5. The present experiments were performed for several days (from 10/6/2004 to 2/7/2004) under different climates, and fixed PV system sloped to the south.

From the analysis of Figs. 4 and 5, it is seen that the cases of N–S and vertical tracking have 30–70% more power than the E–W tracking and the fixed one, which means more utilization of solar energy for power generation. Also, it is seen that the increase in power collection is greater when the sun position is near to sunset and to the early sunshine times in comparison with the fixed system and E–W axes tracking. During the mid day the fixed system has 10–15% less power than other systems, which shows that it is worst position to be used for power generation from the PV collectors. Also, it shows that by using the fixed system there is at least 15% loss of power generation during the mid day hours, and 70% during the morning and evening hours than using the ideal tracking system (N–S). It was found that the energy available from the ideal tracker (N–S) is higher by 3–7% than the vertical and the E–W systems, respectively. The PV system equipped with (E–S)

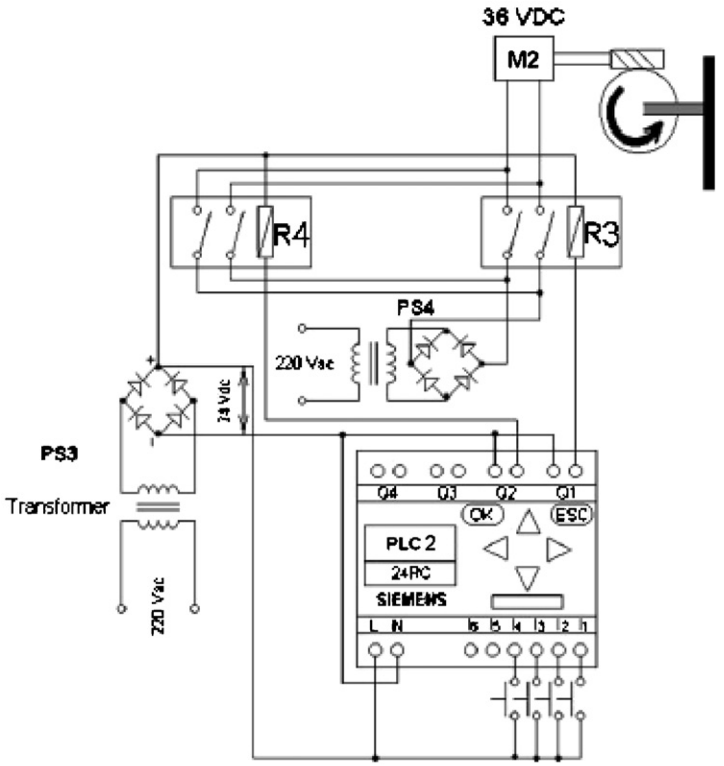

Fig. 3. The electromechanical circuit for slope control.

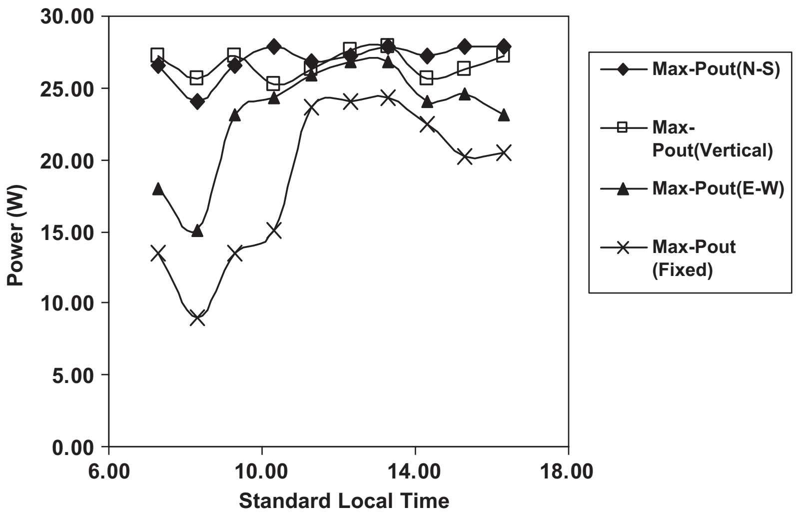

Fig. 4. Power output of different PV systems on 5/7/2004.

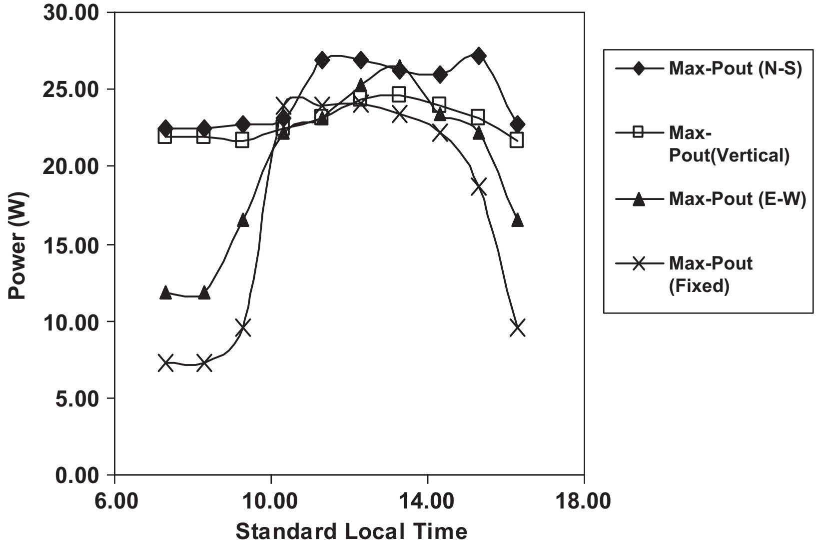

Fig. 5. Power output for different PV systems on 10/6/2004.

sun tracking decreased the power output considerably and was close to fixed one, this phenomena observed by other researchers [33], which shows that a direct sun rays concentration to the PV collectors has affected the functional characteristics of the cells. It can be concluded again that the optimum PV system for providing a favorable condition is the N–S and vertical systems that they have a moderate sun ray's effect on PV cells.

In Fig. 6, we can see that the gain of the accumulated PV energy depends strongly on the type of the MAST system used, as expected. For instance, according to Fig. 6, the 12° sloped south PV collector (the "fixed collector" case is taken as the reference case), produced the lowest energy between all other systems except for the fixed system, that has worst power production. Also it is seen that the gain and the power output are dependent on the slope of the PV, and it can be improved by modifying the system, by using a 32° slope with N–S sun tracking. The PV collector of the N–S sun tracking produces more gains than other systems corresponding to highest power production (Figs. 4 and 5). This represents 25% increase in gain of PV energy compared to the E–W and fixed systems.

A comparison between the two cases of 32° slope with splash and without splash for ideal system (N–S), shows that the PV energy and its gain are dependent on the position of the PV system. For the splash PV system, small loss of gain of nearly 9% occurs for the optimum N–S case. For instance, the gain in PV without splash is around 49%, compared to the case with splashes of 45% for N–S case. This shows that the overall gain is significantly improved compared to the PV with splashes case, this is due to the fact that there are no scatter of the rays, and the total incident radiation is higher. For this optimum case than vertical, E–W and fixed cases those have low power outputs. Also the gain is slightly lower for the vertical case than for the ideal N–S tracking, but higher than E–W and fixed cases.

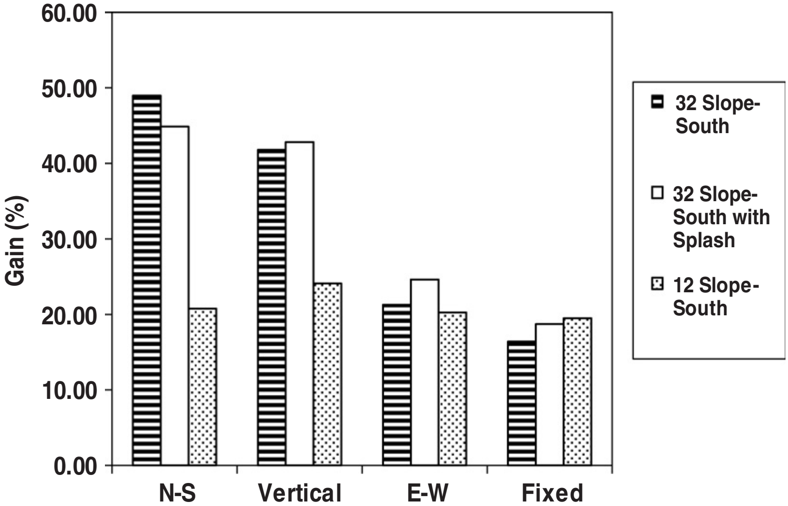

Fig. 6. The gain for different PV systems.

It can be concluded that the use of tracking systems is predictable and significant for different electrical power generation applications, especially in isolated and populated regions away from the national grid. The experimental results showed that a high power was almost always observed at N–S tracking. This finding is supported by previous studies which proved that the tracking system can increase the power output of PV systems, but the present study showed more that the directional mode of the tracking is also important for enhancing the power output. This shows a good potential for PV system for increasing the gain in energy.

8. Conclusion

An experimental study was performed to investigate the effect of using multi-axes-tracking systems on the PV power output. The new systems designed here provided good power output performance. The optimum PV-tracking axis is the N–S that corresponds to the maximum possible power. The power of PV equipped with an N–S sun-tracking system gave much better performance than that of fixed PV systems. Consequently, the integration of multi-axes systems for the power output should be recommended.

It can be concluded, that the use of MAST results in an increase in total power output of about 30–45% as compared with the 32° tilted fixed PV cells. Further studies are already in progress to evaluate the performance of employing these MAST systems in certain solar energy applications in Jordan, such as solar still.

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